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First record of *Stiphodon annieae* Keith & Hadiaty, 2015 (Teleostei, Oxudercidae) from Sulawesi Island, Indonesia

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Abstract

The recently described *Stiphodon annieae* (Keith & Hadiaty, 2015) was thought to be endemic to Halmahera Island, Indonesia. However, from August 2019 to January 2020, we collected several specimens during field trips to the Soho, Simpong, and Uso rivers in Luwuk Banggai, Central Sulawesi, Indonesia. We describe specimens collected in the Soho River and discuss the ichthyofauna of Luwuk Banggai. This is the first report of *S. annieae* from Sulawesi. Our records represent a range extension of approximately 500–600 km west of this species' type locality on the island of Halmahera.

Keywords

Freshwater goby, Luwuk Banggai, range extension, Sicydiinae, Wallacea

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Introduction

Sulawesi, one of the four main islands in the Indonesian Archipelago, is located in the Wallacea region (Whitten et al. 1987). Sulawesi is renowned for its freshwater fish biodiversity, which includes a high proportion of endemic species (Whitten et al. 1987; Kottelat et al. 1993; Hadiaty 2018). Currently, three orders, six families, and 71 species of freshwater fish are known to be endemic to Sulawesi (Miesen et al. 2016; Hadiaty 2018; Mandagi et al. 2018; Kraemer et al. 2019; Kobayashi et al. 2020). Hadiaty and Sauri (2017) discussed the characteristics of the Indonesian freshwater fish fauna and mentioned that the ichthyofauna of western Indonesia is dominated by the order Cypriniformes, while that of eastern Indonesia, including Sulawesi, is dominated by Gobiiformes. While 44% of Sulawesian inland fish species are obligate freshwater fishes (Adrianichthyidae, Telmatherinidae and several limnetic gobies), the remainder are euryhaline and/or amphi-, ana-, or diadromous (Miesen et al. 2016) and are therefore presumed to have a greater capability for dispersal.

Approximately 23% of the freshwater fish fauna of Sulawesi belong to the order Gobiiformes, with at least 16 endemic species of this order inhabiting lakes and rivers (Kottelat et al. 1993; Larson 2001; Hoese et al. 2015; Miesen et al. 2016; Hadiaty 2018). Thirty-six species of Gobiiformes are thought to be diadromous based on their widespread distributions (Keith 2003; Miesen et al. 2016). Recently, a series of discoveries have been made regarding the distribution of riverine and diadromous gobies in the tropical zone (e.g., Maeda and Tan 2013; Tweedley et al. 2013; Keith et al. 2014; Gani et al. 2019); nonetheless, the precise distribution of many species is still poorly known. It is likely that additional studies of the fish biodiversity of Sulawesi, in particular riverine ichthyofauna, will reveal more "widespread gobies".

The Sicydiinae, a subfamily of the gobiid family Oxudercidae, are a highly diverse group of fishes widely distributed over the tropics (Ebner et al. 2011). Many species in this group have an amphidromous life history in which larvae live in the ocean (Keith 2003). Many such species disperse during this oceanic phase (e.g., Watanabe et al. 2006; Iida et al. 2013; Lord et al. 2015). Within this group, the geographic distribution of species is known to differ considerably; some are widespread and others have been found only from one island (Keith et al. 2015). The factors affecting geographic distribution are still poorly understood.

A remarkable sicydiine goby, *Stiphodon annieae* Keith & Hadiaty, 2015 was described from Halmahera Island, eastern Indonesia (Keith and Hadiaty 2015; Fig 1). Known only from and endemic to this island, information about *S. annieae* is limited. This species is known only from two male specimens from the type locality on

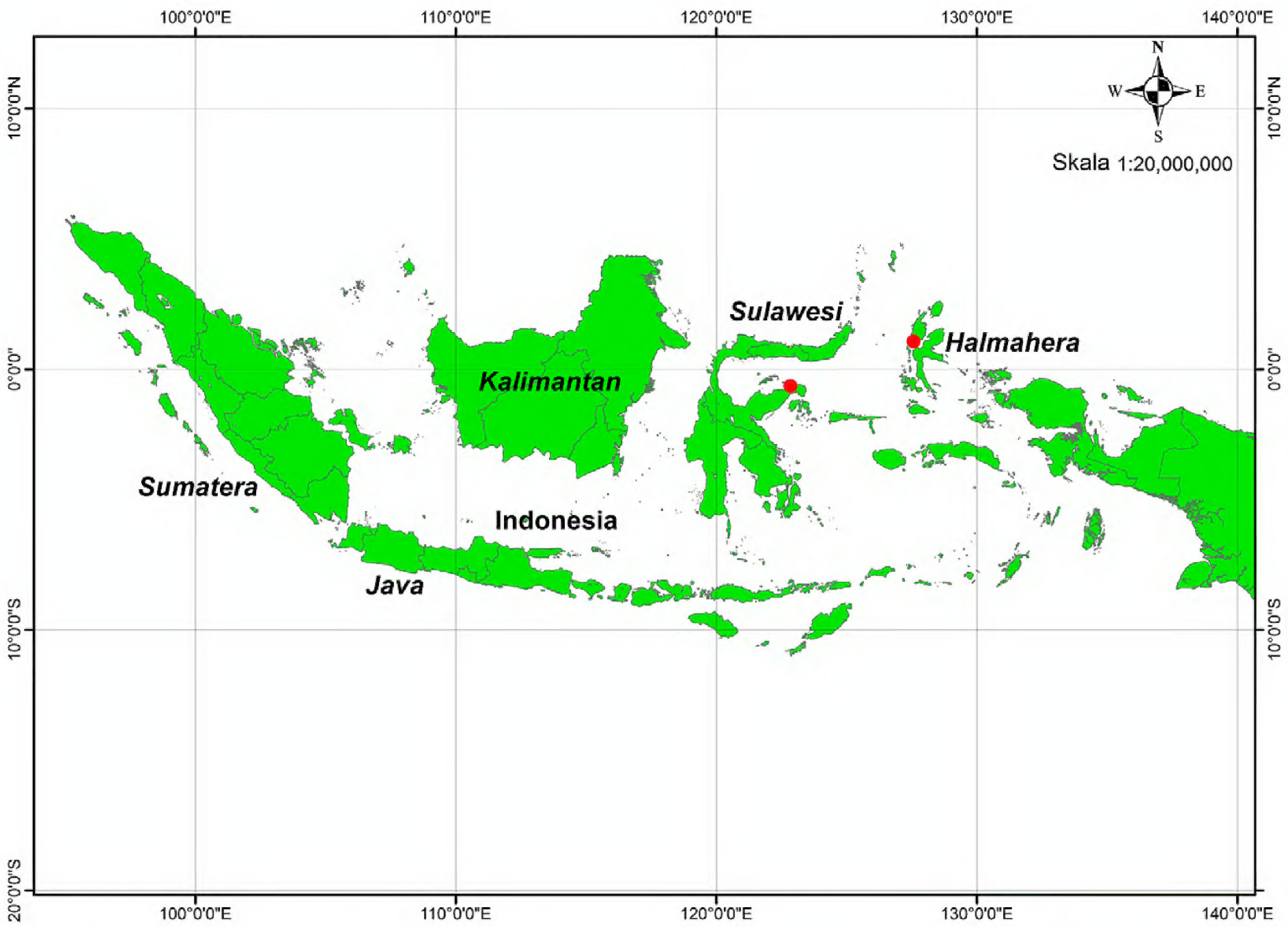

Figure 1. Map of Indonesia showing the recorded localities of *Stiphodon annieae*: the type locality on Halmahera (Keith and Hadiaty 2015) and the new record in Luwuk Banggai, Sulawesi.

the island of Halmahera (Keith and Hadiaty 2015; Keith et al. 2015). *Stiphodon annieae* has not yet been evaluated using International Union for the Conservation of Nature criteria (IUCN 2020).

From August 2019 to January 2020, while exploring sicydiine assemblages in the Luwuk Banggai region on the eastern side of Sulawesi Island, Indonesia, we collected 23 specimens of *S. annieae* (Fig. 2) from three coastal streams. These specimens represent the first records of *S. annieae* from Sulawesi and a significant range extension by approximately 500–600 km west of the type locality (Fig. 1).

Methods

Individuals of *S. annieae* and comparative materials were

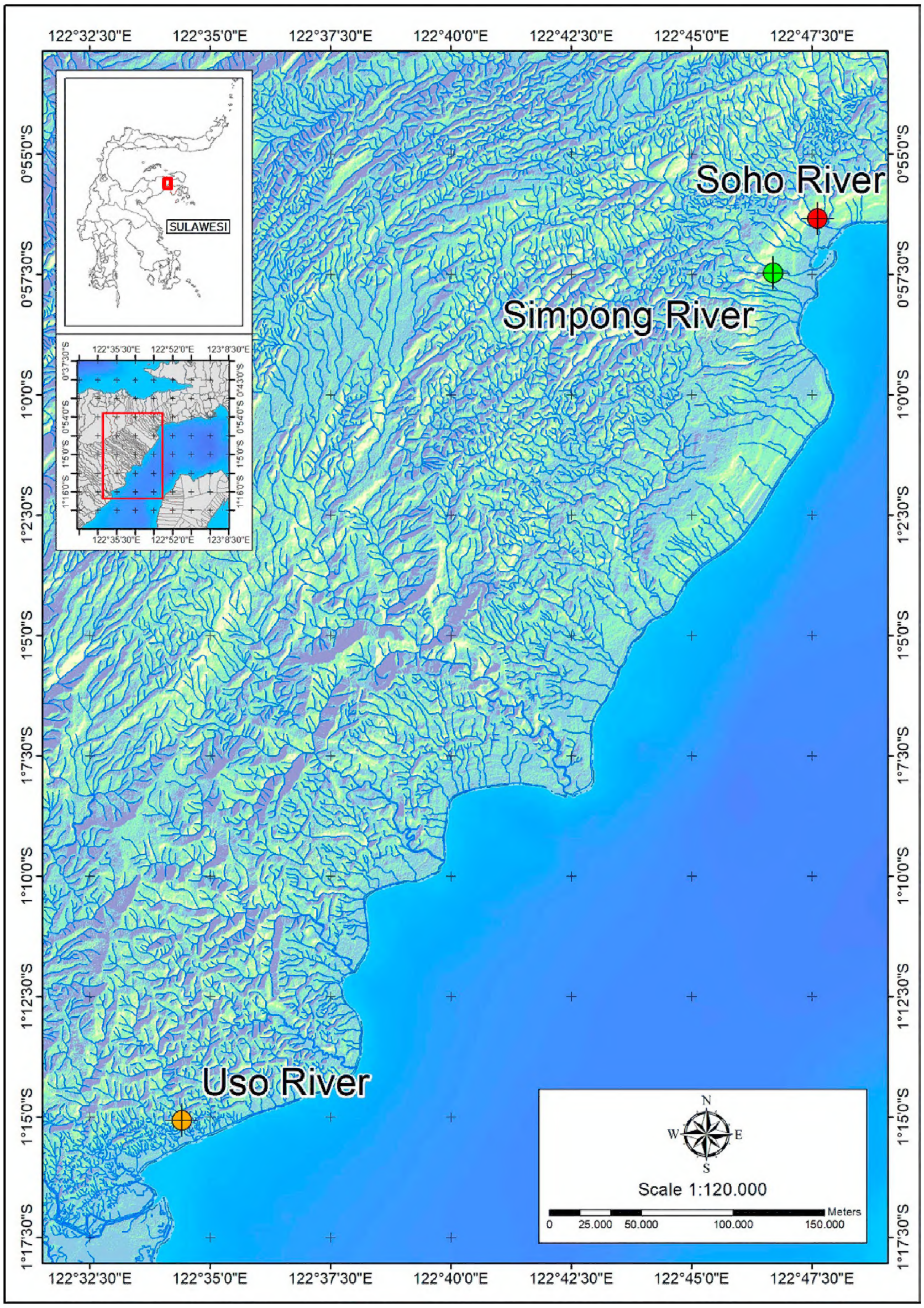

Figure 2. Map of the Luwuk Banggai region in Central Sulawesi showing the locations of the new records of *Stiphodon annieae*. The red, green and, orange symbols indicate the Soho, Simpong, and Uso rivers, respectively.

Figure 3. Habitat of *Stiphodon annieae* in Luwuk Banggai, Central Sulawesi. **A.** Soho River. **B.** Simpong River. **C.** Uso River.

collected using a beach seine. The specimens were collected from the middle reaches of the Soho River (00° 56′20″S, 122°47′37″E), the middle and upper reaches of the Simpong River (00°57′28″S, 122°46′42″E), and the middle reaches of the Uso River (01°15′04″S, 122° 34′25″E) (Figs. 3, 4A–C). We collected 23 individuals in total. The collected specimens were euthanized with MS222, fixed in 3–10% formalin, and then transferred to 70% ethanol for storage. These specimens were deposited in the laboratory of the Fish Quarantine Station of Luwuk Banggai, Luwuk (FCLB), the Marine Science and Fisheries Faculty, University of Hasanuddin, Makassar (MSFUH), the National Museum of Nature and Technology, Tokyo (NSMT), and the Museum Zoologicum Bogoriense, Cibinon (MZB). Identification of the specimens followed Larson (2010), Maeda and Tan (2013), Keith and Hadiaty (2015), and Keith et al. (2015).

Measurements of morphometric characters and meristic counts were obtained from the left side of each specimen collected from the Soho River. Morphometric measurements were taken from point to point using digital callipers with a precision of 0.1 mm. Measurements were reported as a percentage of the standard length (SL) giving the range with the mean value in brackets. Measurements and counts basically follow Keith and Hadiaty (2015); however, measurements not given by Keith and Hadiaty (2015) follow Maeda and Palla (2015). Fin rays and spines, as well as scales, were counted directly under a stereomicroscope (Leica MZ6). Meristic counts were also reported as a range, with mean values in brackets.

Results

Stiphodon annieae Keith & Hadiaty, 2015

Figure 4; Table 1

New records. INDONESIA – Central Sulawesi • Banggai District, Luwuk, middle reaches of the Soho River; 00° 56′20″S, 122°47′37″E; 2.IX.2019; A. Gani, A.A. Bakri and D.T. Adriany leg.; 1 ♂, SL 21.5 mm, FCLB 088/skilb/sp.i/IX/2019 • same locality as the preceding; 18.VIII. 2019; H. Kobayashi, A. Gani, E. Wuniarto and D.H. Satria leg.; 4 ♂, 22.3–25.0 mm SL, MZB 25321–25322 and NSMT-P 139835–139836 • Central Sulawesi, Banggai District, Uso River; 01°15′04″S, 122°34′25″E; 25.I.2020; Nurjirana, A.I. Burhanuddin, E. Wuniarto and A. Gani leg.; 9 ♂, 20.8–21.8 mm SL, MSFUH 1852–1860 • Central Sulawesi, Banggai District, Luwuk, Simpong River; 00°57′28″S, 122°46′42″E; 24/I/2020; Nurjirana, A.I. Burhanuddin, E. Wuniarto and A. Gani leg.; 9 ♂, 21.2–21.8 mm SL, MSFUH 1843–1851.

Identification. The morphological and meristic characters of the specimens collected are provided in Table 1. All specimens collected in the Soho, Uso, and Simpong rivers were identified as males by several specific characters which include: absence of scales on the head, nape, breast, belly, and pectoral base; long head and jaw; pelvic disc adhering to the belly but only between the fifth rays, with a strong fleshy frenum between the spines; bright red flanks, with many blue spots on the dorsal part of the body, from the first dorsal fin to the caudal region; a greenish line from below the eye to the pectoral fin; bright red dorsal fin with black spots; distal blue line on the second dorsal fin; caudal fin bright red, with half blue

Figure 4. *Stiphodon annieae*, NSMT-P 139836 (male, 24.0 mm SL) immediately after fixation.

Table 1. Morphometric and meristic characters of *Stiphodon annieae*.

	Soho River, Sulawesi males, *n* = 4 (this study)	Halmahera males, *n* = 2 (Keith and Hadiaty 2014)
Standard length (mm)	22.3–25.0	21.5–22.7
Morphometric characters (in % of SL)		
Head length	22.8–23.8	25–26
Snout length	7.2–8.1	—
Eye diameter	5.2–6.6	—
Postorbital length of head	11.6–12.1	—
Upper-jaw length	9.1–9.6	10–12
Body depth at pelvic fin origin	12.0–14.3	—
Body depth at anal fin origin	12.8–14.7	—
Depth of caudal peduncle	9.5–12.6	7–9
Length of caudal peduncle from anal fin base	19.2–20.6	12–13
Predorsal length	33.6–36.8	35-37
Length of first dorsal fin base	17.8–21.0	—
Length of first dorsal fin	23.7–30.9	—
Length of longest spine of first dorsal fin	20.4–27.8	—
Interval between first and second dorsal fin bases	0.8–1.7	—
Length of second dorsal fin base	23.2–27.1	—
Length of second dorsal fin	38.1–43.5	30–32
Preanal fin length	54.4–57.7	—
Length of anal fin base	26.5–28.4	—
Length of anal fin	35.2–39.9	30–32
Length between anus to anal fin base	3.6–4.2	—
Length of longest ray of pectoral fin	22.4–23.8	—
Length of caudal fin	26.4–26.6	19–23
Length of pelvic fin	14.0–16.1	—
Meristic counts		
Dorsal fin rays	VI+I, 9	VI+I, 9
Anal fin rays	I, 10	I, 10
Pectoral fin rays	16–17	14
Scales in lateral series	18–19	18–19
Scales in transverse back series	8–9	9
Scales in transverse forward series	8–9	6–7
Scales in predorsal midline	0	0

lines along the margin and in the uppermost part; hyaline pectoral fins with a black patch at the base; whitish belly.

Discussion

Dispersal abilities of amphidromous fishes vary among species and influence distribution patterns (e.g., Kondo et al. 2013; Teichert et al. 2016), but accurate knowledge of the distribution of amphidromous fishes is important, including for estimating their respective dispersal abilities. A study by Tweedley et al. (2013) on the riverine fish diversity of Buton and Kabaena islands off the southeastern peninsula of the Sulawesi mainland, found an ichthyofauna dominated by Gobiidae with just one Sulawesi endemic species. Tweedley et al. (2013) posited that species radiations and, hence, endemism in Sulawesi were concentrated in lacustrine environments, with most riverine species, and in particular the Gobiidae, having a wider distribution due to their amphidromous life cycle.

Species of Sicydiinae are known to vary in their geographic distribution, and *Stiphodon annieae* has been considered to have one of the narrowest distributions within its genus. Until now, *S. annieae* was known only from Halmahera, the type locality (Keith et al. 2015). Such a limited distribution could be due to extremely low ability for dispersal or an adaptation to a fully riverine habitat with shortened larval stage. We discovered *S. annieae* in three unconnected rivers (Fig. 3) in Sulawesi, approximately 500–600 km west of Halmahera (Fig. 1). The mouths of the Soho and Simpong rivers enter the sea less than 3 km apart; the lower reaches of these rivers run through the northern and southern suburbs of Luwuk City, respectively. The mouth of the Uso River is approximately 60 km southwest down the coast from Luwuk.

The range extension documented here suggests that *S. annieae* has the ability to disperse across seaways, as is the case for many other members of the genus *Stiphodon* (e.g., Lord et al. 2015; Maeda et al. 2015). It also opens up the possibility that other gobiid species, such as *Lentipes adelphizonus* Watson & Kottelat, 2006, another species believed to be endemic to Halmahera, may occur in other areas. We believe that it is likely that the distribution range of *S. annieae* is restricted and patchy because we did not find this species during our previous surveys in northern, southeastern, and western Sulawesi (Miesen et al. 2016; Kobayashi unpublished data). To clarify the factors determining the narrow geographic distribution of this species, additional research is needed on its life cycle and ecology. For example, an otolith microstructure analysis, similar to that conducted for three Pacific Sicydiinae (Lord et al. 2010), could estimate the pelagic larval duration.

We identified our specimens as *S. annieae* based on colour pattern and morphological features of males. However, the number of pectoral-fin rays in the specimens from the Soho River was greater than in the type series; fish from the Soho River presented 16 or 17 rays while type material from Halmahera had 14 rays (Keith et al. 2015). Some other morphological traits also differed between these two localities, but only a small number of specimens of *S. annieae* are available for study. These differences could be an artefact of having only two specimens in the type series, or these may indicate divergence, with possible cryptic species involved. These questions might be answered by studying the genetic differentiation between populations. We recommend a combined morphological and genetic population analysis based on more individuals to determine the evolutionary relationship between the two populations.

We also collected female *Stiphodon* specimens, including several different morphotypes, from the same rivers as the males of *S. annieae*. These samples may include females of *S. annieae*, *S. semoni* Weber, 1895, and *S. surrufus* Watson & Kottelat, 1995, but their identification is still pending. In the original description of *S. annieae*, Keith and Hadiaty (2015) had no information

on females of this species. The identification of female *Stiphodon* is relatively difficult, as this genus and other sicydiine genera usually exhibit sexual dimorphism in several meristic traits (Keith et al. 2015). Nevertheless, it was previously thought that *S. annieae* and *S. semoni*, which are sympatric in Sulawesi, could be distinguished by the number of pectoral-fin rays, a trait that does not allow for sexual dimorphism (14 in *S. annieae* vs. 15 in *S. semoni*; Maeda and Tan 2013). However, with the new records and range extension of *S. annieae* in our study, and considering the possibility that both species may be amphidromous and dispersive, we cannot morphologically determine the female of *S. annieae* at this time. Thus, more comprehensive studies on the females of this genus are needed. These should include a description of females of *S. annieae* based on careful survey work backed by identification based on molecular biology methods such as DNA barcoding (Hubert et al. 2016). Well-supported reference sequences of commonly used molecular markers would enable the use of other molecular methods to assist in determining the distribution of *S. annieae* and related species, such as the use of environmental DNA (eDNA) and metabarcoding (Hubert et al. 2016; Lim et al. 2016; Gillet et al. 2018).

Luwuk Banggai, the site of this study, is one of the regions along the eastern coast of Sulawesi where many streams flow into the sea. Gani et al. (2020) recorded 17 species of Gobiiformes from these streams, including a first record from Sulawesi (*Sicyopus discordipinnis* Watson, 1995) and a range extension (*Lentipes mekonggaensis* Keith & Hadiaty, 2015) from the Luwuk area, which together with the current study indicates a high diversity of Gobiiformes in the area. During this survey, we also recorded, for the first time in the Luwuk area, two other species from the Soho River: *Stiphodon surrufus* and *Redigobius oyensi* (de Beaufort, 1913). In addition, Gani et al. (2019) recorded *Sicyopus discordipinnis* Watson, 1995 from the Koyoan River in Banggai District; this species was previously known only from Papua New Guinea and Australia (Ebner et al. 2011; Keith et al. 2015). These findings further highlight the diversity of the gobiid ichthyofauna in the area and the need for more widespread and intensive sampling.

Our discovery of a species in common between Sulawesi and Halmahera islands highlights the complexity and diversity of this region's riverine ichthyofauna, even though there is a dearth of endemic freshwater fishes in this fauna. Freshwater biodiversity is both important and under threat (Dudgeon et al. 2006). We anticipate that continued investigation of the riverine ichthyofauna in Luwuk Banggai and surrounding areas will provide important information, not only for the conservation and sustainable use of these fishes, but also regarding the distribution pattern of amphidromous fishes and the mechanisms determining the formation of these patterns.

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Authors' Contributions

AG, HK, N, and AIB conceived the study. All authors except AMM collected the samples in the field. AG, AAB, DHS, N, and HK identified the species. HK, AG, N, and AAB made measurements. HK, AG, and N took and edited the photograph of the specimen. HK, AG, AMM and N and wrote the manuscript. AG and all authors reviewed, finalized, and approved the manuscript.

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